

Extracting the human nervous system, including the eyes and brain, from the surrounding muscle, bones, and skin is a complex process typically performed in medical or anatomical settings, such as during autopsies, cadaver dissections, or advanced surgical procedures. The goal is to isolate the central nervous system (brain and spinal cord), peripheral nerves, and sensory organs like the eyes while preserving their integrity for study or analysis. Below is a general overview of how this is done, keeping in mind that the process requires precision, specialized tools, and expertise in human anatomy.

General Process of Nervous System Extraction

1. Preparation:

- The body is placed in a controlled environment, such as an autopsy suite or dissection lab, with proper tools (scalpels, forceps, bone saws, etc.).**
- The procedure is performed by trained professionals, such as pathologists, anatomists, or surgeons, following ethical and legal guidelines.**
- The body is typically preserved (e.g., via embalming) to slow tissue degradation, though fresh tissue may be used in some cases.**

2. Accessing the Brain:

- **Scalp Incision:** The skin of the scalp is incised, typically from ear to ear across the top of the head, and the skin is carefully peeled back to expose the skull.
- **Skull Removal:** A bone saw is used to cut through the cranium, creating a "cap" that can be removed to access the brain. This is done carefully to avoid damaging the brain tissue.
- **Brain Extraction:** The dura mater (the tough outer membrane covering the brain) is cut, and the brain is gently lifted from the cranial cavity. The cranial nerves and blood vessels (e.g., carotid arteries) are severed, and the brain is disconnected from the spinal cord at the foramen magnum (base of the skull).

3. Extracting the Eyes:

- **The eyes are part of the nervous system** due to their role in vision and their direct connection to the brain via the optic nerve (cranial nerve II).
- **Orbital Dissection:** The skin around the eye is incised, and the eyelids are separated. The extraocular muscles (which control eye movement) are carefully cut, and the optic nerve is severed at the back of the eyeball.
- **The eyeball is removed from the orbit (eye socket),** preserving the optic nerve if needed for study. The surrounding fat and connective tissue are dissected away.

4. Extracting the Spinal Cord:

- **Posterior or Anterior Approach:** The spinal cord is accessed by removing the vertebral column's bony structures. In a posterior approach, the back muscles are dissected, and the vertebral arches are cut using a bone saw or rongeurs. In an anterior approach, the body is opened from the front, and the vertebrae are accessed through the chest or abdomen.
- **Spinal Cord Removal:** The dura mater surrounding the spinal cord is incised, and the spinal cord is gently lifted out after cutting the spinal nerve roots and disconnecting it from the brainstem.

5. Isolating Peripheral Nerves:

- **Peripheral nerves** (part of the peripheral nervous system) run throughout the body, embedded in muscles, connective tissue, and near bones.
- **Dissection:** Fine dissection tools are used to trace and isolate major nerve branches (e.g., sciatic nerve, median nerve) by carefully separating them from surrounding muscles, fascia, and blood vessels. This is a meticulous process, as nerves are delicate and easily damaged.
- In some cases, only specific nerves are isolated, depending on the purpose of the procedure.

6. Removing Muscle, Bones, and Skin:

- **Skin Removal:** The skin is carefully incised and peeled away from the underlying tissues using scalpels and forceps. This exposes muscles and connective tissues.
- **Muscle Dissection:** Muscles are cut away from bones and nerves using precise incisions. In some cases, muscles are left partially intact if they are closely associated with nerves (e.g., nerve plexuses like the brachial plexus).
- **Bone Removal:** Bones are removed or cut away using saws, chisels, or drills to access the nervous system components. For example, the vertebrae are removed to access the spinal cord, and the skull is opened for the brain.
- **Care is taken to preserve the nervous system structures while removing these tissues.**

7. Preservation and Study:

- **Once extracted, the brain, spinal cord, eyes, and peripheral nerves are typically preserved in formalin or other fixatives to maintain their structure for anatomical study, research, or medical analysis.**
- **In some cases, imaging (e.g., MRI or CT scans) or histological analysis (tissue sectioning) is performed before or after extraction to study the tissues in detail.**

Challenges and Considerations

- **Anatomical Complexity:** The nervous system is intricately connected to muscles, bones, and blood vessels, requiring careful dissection to avoid damage. For example, the optic nerve is fragile and must be cut precisely to preserve the eye's connection to the brain.
- **Time Sensitivity:** Fresh tissue degrades quickly, so extraction must be performed efficiently unless the body is preserved.
- **Ethical and Legal Guidelines:** Dissections are performed under strict protocols, especially for human cadavers, to ensure respect for the deceased and compliance with regulations.
- **Specialized Tools:** Fine scalpels, bone saws, and microdissection tools are used to ensure precision, especially for delicate structures like nerves and the retina.

Specific Notes on Eyes and Brain

- **Eyes:** The eyes are extracted with care to preserve the retina, optic nerve, and associated structures like the lens and cornea. The optic nerve's connection to the brain makes it a critical component of the nervous system.
- **Brain:** The brain is soft and delicate, requiring gentle handling to avoid tearing. The cranial nerves (including the optic nerve) and blood vessels must be carefully severed to remove the brain intact.

Limitations

- **Complete isolation of the entire nervous system (including all peripheral nerves) is rare due to the extensive network of nerves throughout the body. Typically, only major components (brain, spinal cord, major nerves, eyes) are extracted.**
- **The process is destructive to surrounding tissues, so it's not performed on living individuals except in rare surgical cases (e.g., tumor removal).**

Keeping the brain, eyes, and nervous system alive after isolation from the body is an extraordinarily complex challenge that requires replicating the physiological conditions normally provided by the body's circulatory, metabolic, and regulatory systems. No single fluid or set of tools can currently sustain these systems indefinitely outside the body, but short-term maintenance (hours to days) has been achieved in experimental settings using specialized fluids and advanced equipment. Below, I outline the types of fluids and tools used in such experiments, focusing on what is needed to keep the brain, eyes, and nervous system viable ex vivo, along with current limitations.

Key Requirements for Keeping the Nervous System Alive

To maintain the brain, eyes, and nervous system (or parts thereof) in a living state after isolation, the following must be provided:

- 1. Oxygenation:** Neurons and retinal cells are highly metabolically active and require a constant supply of oxygen to prevent cell death.
- 2. Nutrient Supply:** Glucose and other nutrients are essential for cellular metabolism.
- 3. Waste Removal:** Carbon dioxide and metabolic byproducts must be removed to prevent toxicity.
- 4. Electrolyte Balance:** Proper ion concentrations (e.g., sodium, potassium, calcium) are needed for neuronal signaling and cell function.
- 5. Temperature and pH Control:** A stable environment (around 37°C and physiological pH ~7.4) is critical.
- 6. Mechanical Support:** The delicate structures of the brain, eyes, and nerves must be physically supported to prevent damage.
- 7. Sensory/Motor Input:** To maintain functional activity, the brain and eyes may require simulated neural inputs or outputs.

Fluids Used to Sustain Isolated Nervous System Components

No single fluid can sustain the entire brain, eyes, and nervous system, but specialized solutions are used to mimic the body's natural fluids (e.g., blood or cerebrospinal fluid). These fluids are typically circulated through perfusion systems to deliver oxygen and nutrients. Common fluids include:

1. Artificial Cerebrospinal Fluid (aCSF):

- Composition:** A solution mimicking the cerebrospinal fluid (CSF) that bathes the brain and spinal cord, containing glucose, sodium chloride, potassium chloride, calcium chloride, magnesium chloride, and sodium bicarbonate, with a pH of ~7.4.
- Use:** Commonly used in brain slice experiments or isolated nerve preparations to keep neurons viable for hours. It provides nutrients and maintains ionic balance but is not sufficient for long-term survival of whole organs.
- Limitations:** aCSF lacks the complexity of blood (e.g., no red blood cells for oxygen transport or immune components), so it's typically used for small tissue samples rather than whole brains or eyes.

2. Oxygenated Blood Substitutes (Perfluorocarbons or Hemoglobin-Based Oxygen Carriers):

- **Composition:** Synthetic fluids like perfluorocarbons (PFCs) or hemoglobin-based oxygen carriers (HBOCs) can carry oxygen more effectively than simple saline solutions. These are often supplemented with glucose, electrolytes, and buffers.
- **Use:** Used in experimental brain perfusion systems (e.g., BrainEx system for pig brains) to restore partial cellular function in post-mortem brains. For example, in a 2019 Yale study, a solution called BEx solution (a proprietary blood substitute) was used to perfuse pig brains, maintaining some cellular activity for up to 36 hours.
- **Limitations:** These fluids can't fully replicate the immune, hormonal, and regulatory functions of blood, limiting their use for long-term survival.

3. Nutrient-Rich Perfusion Media:

- **Composition:** Customized solutions containing glucose, amino acids, vitamins, and electrolytes, often combined with oxygen carriers. These are tailored to the specific needs of the tissue (e.g., retina vs. brain).
- **Use:** Used in ex vivo eye perfusion experiments to keep retinas functional for hours. For example, studies on isolated rabbit or bovine eyes use modified Krebs-Ringer solution with glucose and oxygen.
- **Limitations:** These solutions are designed for short-term experiments and cannot sustain complex systems like the brain or eyes for extended periods.

4. Plasma or Whole Blood (Modified):

- **Composition:** In some animal experiments, donor blood or plasma is used, modified to prevent clotting (e.g., with heparin) and supplemented with nutrients.
- **Use:** Occasionally used in early brain perfusion experiments, but less common due to ethical and practical challenges (e.g., sourcing compatible blood).
- **Limitations:** Human blood is difficult to use ex vivo due to clotting, immune reactions, and the need for constant replenishment.

Tools and Systems Required

In addition to fluids, specialized equipment is needed to deliver these fluids, maintain physiological conditions, and support the isolated tissues. Key tools include:

1. Perfusion Systems:

- **Function:** Pumps oxygenated fluid through the vascular system of the brain, eyes, or nerves at controlled pressure and flow rates, mimicking blood circulation.
- **Examples:**
 - **BrainEx System:** Used in the 2019 Yale pig brain study, this system includes pumps, oxygenators, and filters to circulate a blood-like solution through the brain's arteries.
 - **Langendorff-Style Perfusion:** Adapted for eyes or small tissue samples, this system circulates fluid through the organ's vasculature.
- **Requirements:** Precise control of flow rate, pressure, and oxygenation to prevent tissue damage.

2. Oxygenators:

- **Function:** Oxygenates the perfusion fluid to ensure adequate oxygen delivery to tissues. This can involve bubbling oxygen or using membrane oxygenators.
- **Use:** Essential for brain and retina, which are highly oxygen-dependent.

3. Temperature Control Systems:

- **Function:** Maintains the fluid and tissue at $\sim 37^{\circ}\text{C}$ using water baths or heat exchangers to prevent hypothermia or overheating, which can kill cells.

4. Bioreactors or Organ Chambers:

- **Function:** Provide a sterile, humidified environment to house the brain, eyes, or nerves, preventing desiccation and contamination.
- **Examples:** Custom chambers used in eye perfusion studies to maintain intraocular pressure and protect the retina.

5. Monitoring Equipment:

- **Function:** Tracks physiological parameters like pH, oxygen levels, and electrical activity (e.g., EEG for brain, ERG for retina) to ensure the tissue remains viable.
- **Examples:** Electrodes to measure neural activity or optical sensors to monitor fluid composition.

6. Neural Stimulation Devices:

- **Function:** Provide electrical or chemical stimuli to mimic sensory or motor inputs, potentially necessary to maintain brain or eye function.
- **Use:** In retina studies, light stimuli are used to keep photoreceptors active; in brain studies, electrical stimulation may be used to mimic neural input.

Specific Considerations for Each Component

1. Brain:

- **Fluid Needs:** Requires a complex blood substitute (e.g., BEx solution) with high oxygen-carrying capacity and glucose. aCSF may suffice for slices but not whole brains.
- **Tools:** Whole-brain perfusion systems with arterial and venous cannulation, oxygenators, and precise pressure control.
- **Challenges:** The brain's high metabolic rate and complexity make long-term survival difficult. Current experiments achieve partial function (e.g., cellular metabolism) but not consciousness or full neural activity.

2. Eyes:

- **Fluid Needs:** Modified Krebs-Ringer or similar solutions with glucose and oxygen for the retina. The optic nerve requires additional support to maintain axonal integrity.
- **Tools:** Orbital perfusion systems to maintain intraocular pressure and deliver fluid to the retinal arteries. Light stimulation may be needed to preserve retinal function.
- **Challenges:** The retina is highly sensitive to oxygen deprivation, and the optic nerve's connection to the brain is hard to maintain ex vivo.

3. Nervous System (Spinal Cord and Peripheral Nerves):

- **Fluid Needs:** aCSF or nutrient-rich saline for short-term nerve preparations. Whole spinal cord perfusion requires more complex solutions like blood substitutes.
- **Tools:** Microperfusion systems for individual nerves or larger bioreactors for the spinal cord. Electrical stimulation may be used to maintain nerve activity.
- **Challenges:** Peripheral nerves are less demanding but degrade without supporting cells (e.g., Schwann cells). The spinal cord is difficult to isolate fully due to its extensive vascular and neural connections.

Current Limitations

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- **Short-Term Viability:** Current technologies can maintain isolated brain tissue, retinas, or nerves for hours to a day at most (e.g., 36 hours in the BrainEx study). Long-term survival (weeks or more) is not possible with existing fluids or tools.
- **Functional Loss:** Even if cellular metabolism is maintained, higher functions like consciousness (for the brain) or vision (for the eyes) are not currently achievable ex vivo due to the lack of sensory input and systemic regulation.
- **Integration Challenge:** No system has successfully kept the brain, eyes, and nervous system alive together as an integrated unit. The optic nerve's connection to the brain and the peripheral nervous system's distributed nature make this extremely difficult.
- **Ethical Barriers:** Human experimentation is limited by ethical concerns, so most research uses animal models or post-mortem human tissue.

Hypothetical Advances

To sustain the brain, eyes, and nervous system long-term, future technologies would need:

- Advanced Blood Substitutes:** Fluids that fully replicate blood's oxygen transport, immune functions, and hormonal signaling.
- Biomimetic Bioreactors:** Systems that mimic the body's mechanical, chemical, and electrical environment, including simulated sensory inputs.
- Neural Interfaces:** Devices to maintain neural activity by simulating sensory and motor pathways.
- Regenerative Support:** Methods to prevent cell death, such as stem cell therapies or neuroprotective agents.

Conclusion

No single fluid or toolset can currently keep the brain, eyes, and nervous system alive indefinitely after isolation. Artificial cerebrospinal fluid, oxygenated blood substitutes (e.g., perfluorocarbons or BEx solution), and nutrient-rich media are used in experimental settings, combined with perfusion systems, oxygenators, and bioreactors, to maintain partial function for hours to days. The brain requires complex perfusion systems like BrainEx, eyes need specialized orbital perfusion, and nerves can be sustained with simpler solutions like aCSF. However, integrating these systems and achieving long-term survival or full functionality remains beyond current capabilities.

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